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A Study of the Periodontium Following Orthodontic Closure of Extraction Sites in the Macaca Nemestrina

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A STUDY OF THE PERIODONTIUM FOLLOWING ORTHODONTIC CLOSURE OF EXTRACTION SITES IN THE MACACA NEMESTRINA

by

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BIOGRAPHY

I was born on a small cotton farm on August 2 , 1937 near Crossroads, Mississippi, south of Tucker Indian School. There was no attending physican. My father worked as a coal miner, in the steel mills, defense plants and petroleum plants. In 1943 my family moved to Baton Rouge, Louisiana where I attended Istrouma Elementary, Junior High, and High School. I attended Louisiana State University from 1955 to 1959. This education was made possible by an athletic scholarship. I ran track and played football achieving All-American honors in 1958 and 1959, also being awarded the Heisman Trophy in 1959. I played professional football from 1960 to 1963 with the Houston "Oilers" from 1963 to 1970 with the Oakland "Raiders" and 1970 to 1971 with the Kansas City "Chiefs". I enrolled in the University of Tennessee Dental School in 1963 and graduated from that institution in 1969. This education was made possible by a leave of absence granted each year to pursue my career as a professional football player. I joined the Loyola Orthodontic and Oral Biology Departments in 1969. Following graduation, I plan to practice Orthodontics in Baton Rouge, Louisiana.

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I wish to thank Dr. Ravindra Nanda for his dedication and time spent in completion of this investigation. Without his help and boundless knowledge in this field, this research could not have been possible. I also wish to thank Mr. Ted Flora for his tremendous support in the handling of the monkeys.

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INTRODUCTION

The experimental studies relating to the orthodontic tooth movement have been of great interest to the orthodontist as it is difficult for him to envision and relate the changes observed clinically and those actually transpiring at the histological level.

The present investigation was undertaken to study the orthodontic movement of the cuspids through the extraction sites compressed immediately after the surgery and through those not compressed. This problem is of vital importance to orthodontists as the procedure of the compression of the extraction sites is relatively common after the surgery to aid in the healing process. No comparable study in the literature was found. It is wished the results of the present study will provide additional information on the tooth movement at the histological level. It is further hoped the results will be applicable in the everyday orthodontic practice.

REVIEW OF LITERATURE

The approximation of teeth in orthodontic treatment is a relatively simple problem for the present day specialist. However, retaining orthodontically treated teeth in their newly acquired position in the dental arch and periodontium is an ever present problem to be reckoned with. In the past, numerous investigations have been conducted to study the normal periodontium and its associated changes during and after the orthodontic treatment. These studies enhanced the understanding of the basic biology of the periodontium, the various causes of relapse and ways to prevent them.

Kinglsey (1880), in the first American text on orthodontics, described the alveolar bone and its response to forces applied to the teeth. He stated that orthodontic tooth movement occurs due to the elasticity of alveolar bone. Farrar (1888) later claimed orthodontic tooth movement as a result of resorption and apposition of bone.

The first scientifically conducted experiment to study the response of tissue due to orthodontic tooth movement was performed by Sandstedt (1901, 1904). He placed orthodontic appliances on the teeth of dogs and provided histologic evidence that bone apposition occurs on tension side and resorption on the pressure side. He also was the first investigator to describe the phenomenon of "undermining resorption". His conclusions confirmed Flourens' theory (1842) that pressure' was the cause of orthodontic tooth movement.

Oppenheim in his earlier studies (1911) disagreed with the conclusions of Sandstedt (1901, 1904) and stated that orthodontic tooth movement was not the result of pressure and tension but rather by modulation of the entire bony structure. However, later (1934) he disagreed with his above mentioned conclusion.

Schwarz (1928, 1931, 1932a, 1932b) duplicated the experiments of Sandstedt on dogs and confirmed the latter's findings. He described the four degrees of biologic reaction incident to orthodontic tooth movement. In the first degree of biologic reaction the force is so slight that no reaction occurs; in the second degree, the force is less than the pressure of blood capillaries; in the third degree, the fairly strong force represses the pressure of the blood capillaries and in the fourth degree, the force is strong and "undermining resorption" is observed. He concluded that a force of 20 gm/sq. cm. of bone area is optimum for biologic movement of a tooth by orthodontic means.

Johnson et al. (1926) utilized monkeys to ascertain the nature of the tissue changes resulting from tooth movement by means of an orthodontic appliance. The findings revealed that the direction of trabeculae of alveolar bone conforms to the direction of tooth movement.

Skogsberg (1926) made the first attempt to explain and resolve the problem of relapse of orthodontically rotated teeth. He proposed that an incision of supra-alveolar fibers of orthodontically repositioned teeth would prevent their returning to the original position. He believed that orthodontic relapse was due to an "elastic cortical substance which his septotomy would neutralize". Talbot (1896) also described a similar surgical operation before the orthodontic treatment to aid in the moving and rotation of teeth in a certain direction.

Beckwith et al. (1927-1927) investigated the regeneration process of the periodontal fibers of rats after experimental injury. The regeneration, which was found to be evident after 3 to 7 days, started at the tooth surface rather than from the alveolar surface. The repair of bone commenced after the reconstruction of the periodontal fibers. Beckwith and Williams (1928) later studied regeneration of the periodontal fibers in the cat and confirmed their earlier findings.

Marshall (1930) studied histologic effects of orthodontically caused extrusion and intrusion of the periodontium of the central incisors of macaca rhesus monkeys. He found that with the elongation of teeth the transseptal fibers become parallel to the long axis of the root and all other periodontal fibers show direction of the stress. After intrusion a reverse arrangement but to a lesser degree, was observed. Later, Lefkowitz and Waugh (1945) demonstrated on two young dogs by means of histologic sections that tooth intrusion is possible by orthodontic appliances. They also showed that bone resorption can occur under tension as well as under pressure. They concluded from their findings that continuous force is better tolerated by the periodontium than intermittent stress.

Dellinger (1967) in a recent study on monkeys concurred with the findings of Lefkowitz and Waugh (1945). He also stated that 50 grams of force gave optimal intrusion and that root resorption did not appear to be related to the distance that teeth were intruded.

Urban et al. (1931) conducted a histologic investigation of the periodontium of dogs after orthodontic tooth movement. They found that the periodontal fibers could be stretched 0.75 to 1.5 mm before tearing occurred. The fibers tore in the middle of the ligament rather than from the bone or cementum.

Herzberg (1932) was the first to move a human tooth with an orthodontic appliance and study its periodontium. He observed that adjacent to the tooth on the tension side, spicules of bone were formed which were arranged parallel to the direction of the force.

Oppenheim in 1934 stated that the supra-alveolar fibers form the most resistive tissue with which orthodontists deal. Skillen and Lundquist (1937) studied regeneration of the supra-alveolar group of periodontal fibers of dogs after making artificial periodontal pockets up to a depth of 7 to 8 mm. They found that the area of reattachment of connective tissue to the tooth surface was very small in as much as epithelial tissue proliferated over the denuded connective tissue much faster.

Skillen (1940) later reported that all injuries except those affecting the gingivae seem to heal readily, with no apparent functional defect. He also stressed that recovery of gingivae and the possible effects of their injury are much more serious.

Skillen and Reitan (1940) described the arrangement of periodontal fibers of dogs coincident with orthodontic tooth movement. They showed by histologic sections that after only 28 days of retention following orthodontic treatment the majority of the bundles of periodontal fibers were rearranged. However, they observed a slow reorientation of periodontal fibers in the transseptal and gingival areas. They asserted that rearrangement of the bony portion required approximately 83 days. Whereas, the supra-alveolar group of fibers was found to be markedly stretched and displaced even after 232 days of retention. With this information they concluded that the lack of rearrangement of the supra-alveolar groups of fibers was the major cause for the relapse regardless of the time of the retention period.

Waldron (1942) reviewed the problem of retention and concluded that transseptal fibers from an integral part of the periodontium. He believed that the breaking of these fibers interferes with the function of maintaining proper mesio-distal relationship of adjacent teeth. Thus, their benefit during retention is lost. However, his theory has not been substantiated by the majority of the recent studies.

Bunch (1942) conducted experiments on dogs to investigate the tissue changes incident to depressing movements resulting from orthodontic appliances. His histologic results substantiated the clinical finding that an interval of time elapses after the application of a depressing force until clinical depression occurs. He could not explain why this initial stationary phenomenon occurred.

Chase and Ravez (1944) studied regeneration of transseptal fibers in monkeys following extraction of deciduous teeth and approximation of extraction sites. They showed reorganization of interrupted transseptal fibers at the extraction site after five weeks. They also observed an increase in the interdental fibrous tissue after the closure of the extraction site.

In 1945 Erikson et al., using human specimens, confirmed the findings of Chase and Raves (1944). They demonstrated that following extraction the presence of transseptal fibers was remarkably persistent even when all the bony support was lost. They found elongated transseptal fibers in the spaces created by tooth extraction. After approximation of extraction sites they noted that transseptal fibers remained relaxed, coiled, and compressed in the nature of the scar tissue. No shortening or removal of the excess fibers was observed after approximation of teeth adjacent to the extraction site. However, a compression of these fibers caused crushing injuries to the periodontal membrane, alveolar bone, cementum and even dentin. They concluded that it is biologically unsound to expect good approximal contact between dental units after closure of extraction sites.

Aisenberg (1948) stated that the supra-alveolar group of fibers do not readily react and readapt following orthodontic tooth movement. He concluded that this characteristic of these fibers may be a principal factor in relapse.

Linghorne (1950, 1957) studied regeneration and reattachment of the supporting structures of the teeth in dogs. He showed that in the reattached gingiva, the connective tissue fibers run in a direction parallel to the tooth rather than in the characteristic oblique arrangement.

Arnim and Hagerman (1953) conducted an extensive investigation of the nature and arrangement of marginal fibers of gingivae of rats, monkeys and humans. They found circular fibers in the marginal gingiva which entered the cementum, alveolar bone or coursed between the fibers of the transseptal group. Some of these fibers were attached to neither cementum nor bone, but ran their full length in the marginal gingiva itself. They named these fibers "ligamentum circulare". The importance of these fibers along with transseptal fibers in retention after orthodontic tooth movement has been stressed by several recent studies.

Macapanpan and Weinmann (1954) studied the influence of injury to the periodontal fibers after placing a piece of rubber dam between the upper molars of Sprague-Dawley rats. They concluded that trauma causes damage to the periodontal fibers not only on the pressure side but also on the tension side.

Reitan (1947, 1951, 1953, 1954, 1957, 1959, 1960a, 1960b, 1962, 1964, 1967) has done extensive work in the field of tissue reactions resulting from orthodontic tooth movement. He found that orthodontic rotations of teeth caused a marked displacement and stretching of the supra-alveolar group of fibers of the periodontal membrane. He observed these fibers to remain in a stretched position even after long periods of tooth retention. He contended that the supra-alveolar fibers played a great role in the relapse of rotated teeth. Reitan has also demonstrated the histological changes of the periodontal fibers incident to intrusion, extrusion, tipping and bodily translation of teeth.

Storey (1953) described four zones of activity around a tooth which was being moved with light orthodontic forces. He noted that the newly formed bone on the tension side of the tooth socket wall was undergoing resorption and spongy supportive bone eventually replaced the lamina dura which progressively reformed as it followed behind the moving tooth. On the pressure side of the tooth socket, ahead of the area of resorption was an area of apposition where the lamina dura was continually being reformed in advance of the approaching tooth.

Huettner et al. (1955) investigated the periodontium of vital and non-vital teeth of macaca rhesus monkeys relative to their ability to move. They found no apparent differences in the bone, periodontal ligament and cementum of vital and non-vital teeth after application of a force of 2 ounces. Huettner (1958, 1960) in other investigations studied the changes in the periodontium of teeth of monkeys after extrusive, intrusive, tipping, bodily and rotational movements. He found that elongation with a round wire and 2 ounces of force caused minimal root resorption and observed new bony spicules at the apical end of the root. He showed that torquing central incisors with a force of 9 ounces caused great damage to the periodontium.

Thompson (1955, 1958, 1959a, 1959b) reported in a series of articles on the regeneration and the potentialities of the periodontal fibers incident to orthodontic tooth movement. He proposed the theory that while the fibers of the periodontal membrane were composed of non-elastic white collagen, the physical waviness of the fibers could produce a force in sufficient amounts to cause rotational relapse.

Goldman (1957) described the behavior of the transseptal fibers in periodontal disease. He showed in the edentulous area, between two teeth, the formation of collagen fibers which functions as a transseptal group. He (1954, 1962) has also explained the arrangement of normal periodontium in detail in his numerous studies and textbooks (1964).

Burstone (1962) described three phases of orthodontic tooth movement; the initial phase, comprising the displacement of the tooth in the periodontal membrane space; the lag phase, a period in which the tooth did not move or had a relatively low rate of displacement; and the postlag phase, in which rate of movement increases gradually or suddenly. He gave precise measurements for the location of the center of resistance of a single-rooted tooth with a parabolic shape. He stated that it was a point 0.4 times the distance from the alveolar crest to the apex.

Burket (1963) stated that after closure of extraction sites by orthodontic means, transseptal fibers become coiled or bunched, and thus can produce abnormal pressure on the periodontal ligament and alveolar process resulting in injury. He believed that because of "malpositioning of the transseptal fibers" a permanent good contact between approximated teeth over the extraction site can never be achieved.

Utley (1968) studied the activity of alveolar bone associated with orthodontic tooth movement with the help of oxytetracycline - induced flourescence. He stated after comparing experimental and control sections that the structural dynamics and osteogenic activity of alveolar bone were increased in response to orthodontic tooth movement and its accompanying forces.

Wiser (1961) supported the work of Skogsborg (1926). He rotated the maxillary central incisors of 4 dogs and performed simple gingivectomies on the right first and second incisors leaving the left ones as controls. The retention period was two weeks and the relapse period ranged from 2 to 6 weeks. The left incisors showed four times greater relapse compared to those incisors which had gingivectomy. The surgical group had a mean relapse of 11.2 % as compared to 43.8 % by the control group. Wiser attributed the relapse of 11.2 % to a short 2 week period of retention which he assumed was not enough for the reorganization of principal collagen fibers of the periodontal membrane.

Tsopel (1967) repeated the experiments of Wiser but "employed a less traumatic surgical approach". He rotated the maxillary right and left first and second incisors in 3 dogs and transsected the transseptal fibers by making vertical incisions interdentally to the bone. The gingival fibers were sectioned by lingual and labial incisions of one to two millimeters from the crest of the alveolar ridge. His results did not concur with those of Wiser (1961). He suggested that the sectioning of the supra-alveolar fibers does not prevent the relapse of rotated teeth. In fact, in Tsopel's study the experimental group subjected to surgical transsection of their supra-alveolar group of fibers showed a 14 % higher relapse tendency than the non-surgically treated teeth.

Edwards (1967, 1968) studied the periodontium after rotation of teeth in 6 young dogs. He demonstrated that the fibers of the gingiva do remain attached to the tooth during orthodontic rotation, which results in displacement of the gingiva in the direction of tooth movement. He found that after 5 months of retention, transseptal and gingival fibers were still tense and oriented in the direction of rotation. Atherton (1970) described the gingival changes in the extraction area after the approximation of adjacent teeth. He showed a "piling-up" of gingival tissue between two orthodontically approximated teeth. He concluded that teeth moving through the extraction space tended to displace the gingival tissue rather than move through it. Edwards (1971) in another study confirmed the findings of Atherton and also found that orthodontically approximated teeth do not move through gingival;tissue but rather push the gingiva into the new interproximal area. He believed that the excess tissue compressed between the teeth might be responsible for a relapse in the area. Edwards suggested surgical removal of the buccal and lingual folds of excess tissue.

Brain (1969) observed that transsection of the free gingival fibers greatly reduced the incidence of relapse of these teeth was 24 times less than the degree of relapse of rotated teeth in the control animals. This finding is contrary to that of Tsopel's (1967) but concurs with those of Wiser (1961) and Edwards (1967, 1968).

The contribution of Sicher (1923, 1942, 1959, 1962, 1965) in the understanding of the development and arrangement of the periodontal fibers is of considerable importance. He was the first to report the existance of the "intermediate plexus" within the periodontal ligament. Sicher's initial subjects were rats and guinea pigs, but later he observed an intermediate plexus in humans too. He proposed that movement of teeth in respect to the alveolar bone does not occur by a new attachment as described by Reitan but by the formation of new links between the alveolar and dental fibers in the intermediate plexus. Sicher also described a similar intermediate plexus an transseptal group of supra-alveolar fibers. Eccles (1959) and Trott (1962) however, could not find an intermediate plexus in the periodontal membrane of the molar teeth in the rat, but both Hunt (1959) and Goldman (1962) described the presence of "intermediate plexus" in the periodontal membrane of guinea pigs and spider monkeys, respectively, in a number of studies. In rats studied both radiographically and histologically, Crumly (1964) did not find an intermediate plexus with either normal or repositioned teeth. He supported his results by showing relatively greater and faster uptake of H^3-proline by the forming collagen fibers attached to the lamina dura of the alveolar bone as compared to the collagen fibers attached in the periodontal ligament's center region or the so-called region of intermediate plexus. He also demonstrated the collagen formatin at the cemental side was the slowest.

Zwaryche and Quigley (1965) could not find the "intermediate plexus" in the periodontal fiber bundles running from cementum to the alveolar bone. They found more fibers but less bundles inserting into the cementum whereas the reverse phenomenon was observed on the side of alveolar bone. They concluded that a force applied to a given area of cementum was passed along by the fibers to a greater area of alveolar bone. Zwaryche and Quigley asserted that osseous changes and not an adjustment in the intermediate plexus allowed for tooth movement in the rat.

OXYTALAN FIBERS

Fullmer and Lillie (1958) demonstrated a staining technique which revealed the presence of new soft tissue fibers in the periodontal membrane. These fibers were found to be resistant to acid hydrolysis,because of this characteristic they were named oxytalan or acid enduring fibers. Oxytalan fibers were distinguished histochemically from other types by their staining reactions. Neither collagen and reticulum stains nor regular procedures for elastic tissues deomstrate these fibers. They can be identified with three of the elastic stains (Orcein, resorein fuchsin and aldehyde fuchsin) but only after strong oxidation. Because of this different histochemical property, they suggested that oxytalan fibers are pre-elastic or specially modified elastic fibers.

The presence of oxytalan fibers has been demonstrated in many tissues. They are found in the periodontal membranes, tendons, ligaments, blood vessels, mucous connective tissues and pathological tissues of oral cavity and skin (Fullmer and Lillie, 1958; Fullmer, 1959a, 1959b, 1960a, 1960b, 1961, 1962; Fischer and Fullmer, 1962; Fullmer and Witte, 1962; Tedeschi and Sommers, 1961, 1962; Hasegawa, 1960).

Fullmer (1964) reported that the largest and most numerous oxytalan fibers are present in the transseptal region of both the deciduous and permanent dentition of humans. These fibers were found to be scarce and smaller in diameter in the middle of apical areas of the periodontal membrane as compared to the supra-alveolar area. The oxytalan fibers along with the collagen bundles are inserted into either the cementum or the bone. Fullmer (1966) observed that more oxytalan fibers insert into cementum than into alveolar bone. He further stated that oxytalan fibers do not run the width of the ligament from cementum to bone or from tooth to tooth. Fullmer (1964, 1966) also demonstrated that in the gingiva, the oxytalan fibers followed the paths of the free gingival fiber groups. These fibers were also seen following the directions of circular fibers.

An electron microscopic study by Carmichael and Fullmer (1966) revealed oxytalan fibers as round, elliptical, or flattened in cross-section and the longest fibers were found to be 2 mm long. The fibers are composed of many filiments approximately 100 Å in diameter with an amorphous interfibrillar material of apparently the same thickness.

Several authors have confirmed their findings (Lieberman, 1960; Moura, 1966; Kohl and Zander, 1962; Baratieri, 1967).

Rannie (1961) modified the histochemical technique of Fullmer and Lillie and demonstrated that the fibers run vertically around the apex and root but horizontally at the neck of the tooth.

Goggins (1966) found only minor differences in the distribution of oxytalan fibers within the periodontal ligaments of deciduous and permanent dentitions. The permanent dentition showed more fibers embedded in cementum and less fibers in the middle thirds of roots than in the deciduous dentition.

Several authors have discussed the role played by oxytalan fibers in the maintanance of the periodontium and in the other areas where they are found. However, the opinions differ widely. It has been reported that oxytalan fibers are present in areas of tissue repair of the periodontium, but at the same time it has not been established whether they play any significant role before, during or after the reparative process (Fullmer, 1961, 1962). Rannie (1961) could find no evidence as to the function of these fibers but he postulated that in as much as these fibers are woven through the collagen fibers and are embedded in bone and cementum, they may have some anchoring effect to preserve the periodontium. Löe and Nuki (1964) stated that scarcity of these fibers precludes any significant tooth supporting function. Contrary to the observations of others, these two authors postulated that oxytalan staining fibers are nerve fibers.

In the field of orthodontics much attention has been given to the observations of Fullmer (1964) and Rannie (1961) that the size and number of periodontal oxytalan fibers are greater in the areas of increased stress. Edwards (1968) reported that oxytalan fibers became larger and more numerous during orthodontic tooth movement in dogs. His results were later confirmed by Boese (1969) who worked on monkeys. However, much information is lacking regarding the role of oxytalan fibers in orthodontic tooth movement and retention of the moved teeth.

MATERIALS AND METHODS

The Macaca nemestrina monkey was employed for the experiments of the present study. It has been shown that monkeys have their dentition similar to that of human beings and the eruption pattern and growth curves are the same as found in humans (Shultz, 1935; Van Wagenan and Catchpole, 1956). Mills (1955) has shown that the working and balancing bite of the macaque monkey is identical to that of humans. Furthermore, the above mentioned authors have pointed out that besides the similarities of dentition, eruption pattern and growth curves, the monkey is of great value as an experimental animal because it belongs to the same order as man.

Three adult Macaca nemestrina monkeys with complete permanent dentition were utilized for the experimental procedures. The monkeys all had an angles class I molar relationship without any evidence of malocclusion. All the monkeys were female. No separate control monkeys were employed as in each monkey the lower right quadrant served as the control.

The animals were kept at Loyola University Animal Research Center. The animals were housed in 3' x 5' x 3' metal cages with a movable wooden back serving as a "squeeze" for animal control. The humidity, temperature and light of the animal room were controlled at all times. Monkeys were fed with Purina Monkey Chow which was soaked in water to make it soft. Fresh fruits, such as, chopped apples, bananas and oranges, were given daily. Water was available ad libitum.

Surgical Procedure

The maxillary and mandibular right and left first bicuspids were extracted in all of the animals. The extractions were performed by anesthetizing the animals with intramuscular Sernylan*. Approximately 2.0 mg of Sernylan per kilogram of body weight was administered to the monkeys. The body weight of the monkeys varied from 4-6 kilograms. The narcosis lasted from one to one and a half hours. The extractions were performed with pedodontic surgical forceps. The root tips of extracted first bicuspids were carefully examined to assure that no root tips were left in the extraction site.

Immediately following the surgery, five extraction sites in three monkeys (Table I) were "compressed" with fingure pressure to aid in the healing. A moderate pressure was applied. Care was taken in exerting approximately the same amount of pressure. The extraction sites in the remaining seven quadrants were not compressed.

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*Bio-centric Laboratories, Inc. St. Joseph, Mo. 64502

Placement of Appliance

Orthodontic appliances were placed in three quadrants of each monkey, with the lower right quadrant serving as a control. The appliances were placed 7 days after extraction. The monkeys were anesthetized with intramuscular injection of 2 mg. Sernylan per kilogram of body weight.

Ormco** bicuspid blank bands were used for first permanent molars and lower anterior blank bands for cuspids. All blank bands had non-angulated, non-torqued .018 x .025 edgewise brackets. Band-pinching pliers were used to fit the bands snugly on the teeth. The bands were cemented with Durelon*** (carboxylate cement). Sufficient time was given for the hardening of the cement. Immediately following the placement of bands, a segmented cuspid retraction appliance was placed (fig. 1). The segmented arch was made of .016 x 0.22 stainless steel wire. The wire was heat treated at 800^{o}F for 2 minutes before the insertion. The segmented arch wire was tied to the broche of the bands with .010 stainless steel ligature wires. The anterior end of the wire was bent over at the mesial surface of the cusipd bracket and the distal end was activated by pulling the wire distally until a force of approximately 4 to 5

**Ormco 1332 S. Lone Hill Ave., Glendora, California

ESPE, GmbH Seefeld/Oberbay, W. Germany ounces was achieved. The force was measured with a Dontrix* gauge.

The entire procedure of appliance construction and insertion took 1 to 2 hours per monkey. The appliance was reactivated every 14 days. Approximately 4 ounces of force was applied at later reactivations.

Special precautionary care was taken to prevent the monkeys from manually removing or breaking the appliances. This was done by placing around their necks and shoulders dual modified Elisebethean collars (fig. 2). The lower collar was 1/16 inch thick plastic reinforced with brass plates and bradded aluminum bolts. The upper collar was 1/8 inch thick and made of aluminum. It was circular in shape and the outer-diameter was 10 inches and the inner diameter was made to fit each monkeys neck. Enough freedom was given to the neck and shoulder collars for comfort and mobility to the monkey.

Appliance Care

Visual inspection of the appliance and the retraction sites was made twice daily at the feeding periods by Animal Research Laboratory Supervisor. A close visual examination was possible

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****Rocky Mountain Dental Products P.O. Box 1887, Denver, Colorado, 80201 by utilizing the squeeze part of the cage. Every Friday night the monkeys were anesthetized to measure the extent of cuspid retraction and for inspection of appliances. Loose bands, broken wires or bent appliances, if any, were replaced during this inspection period. Every second Friday night besides the necessary repairs, the standard activation of the appliance was performed.

Weekly prophylaxis and oral stimulatory massage was performed with hand instruments and a battery operated electric tooth brush. All monkeys were placed on tetracyline medication for three days twice during the experiment for prevention of infection.

Records

Lateral cephalometric head plates were taken prior to and after the conclusion of the experimental procedure. Intraoral photographs were taken prior to, during and after the different phases of the experiment.

Sacrificing of Animals

The monkeys were anesthetized with Sernylan using the dosage previously described.

The left leg of the monkeys was shaved and 300 mg of sodium pentobarbital was injected intravenously. The death occurred instantaneously. The monkeys were decapitated with a sharp knife. The facial skin, muscles and oral mucosa was removed with a Bard-Parker knife. The mandible and maxilla were disjointed with an electric saw. Each quadrant was cut distal to the lateral incisor and distal to the first molar using a Stryker saw. Special care was taken to include the apices of all teeth which were involved in the orthodontic treatment. At this stage the appliances were removed from the teeth.

Histological Procedures

Immediately following sectioning, the quadrants were placed in a 10% formalin solution. The formalin solution was changed every day for 5 days.

Following fixation, the specimens were decalcified using the formic acid-sodium citrate method. The decalcification period ranged from 2 to 3 weeks. The extent of decalcification was observed by roetgenograms. After decalcification the specimens were trimmed to a desired size, washed for six hours, dehydrated, and embedded in paraffin. The sections were cut at 7 microns thicknesses.

The sections were stained with haemotoxylin-eosin and Gamori's trichrome stain. For oxytalan fibers, the staining method employed by Fullmer and Lillie (1958) and modified by Rannie (1961) was used. The method is as follows:

1. Deparaffinize and bring sections to absolute alcohol
2. 10 % oxone....................................60 minutes
3. Running water.................................. 2 minutes
4. Gamori's aldehyde fuchsin...................... 8 minutes
5. 95 % alcohol................................... 2 changes
6. 95 % alcohol................................... 5 minutes
7. 70 % alcohol...................................   rinse
8. Running water.................................. 2 minutes
9. Weigert's haemotoxylin......................... 4 minutes
10. Running water..................................60 minutes
11. Acid alcohol...................................30 seconds
12. Running water.................................. 2 minutes
13. Halmi's counterstain...........................20 seconds

Distilled water	-	100.0 ml
Light green SF	-	0.2 gm
Orange G	-	1.0 gm
Phosphotungstic acid	-	0.5 gm
Glacial acetic acid	-	1.0 ml

14. 95 % alcohol (0.2y acetic acid)...................   rinse
15. Dehydrate and mount

OBSERVATIONS

VISUAL EXAMINATION:

The three monkeys were examined regularly as previously stated, during the orthodontic retraction of cuspids. The healing of the extraction sites appeared normal.

No difference in time required for healing of the extraction sites was observed between those sites which were "compressed" immediately following the surgery and those which were not. Fourteen days following surgery all of the extraction sites appeared to be healed.

The distal movement of the cuspid was measured every week and the results are shown in Tables I and II and figs. 2, 3, and 4. During the first week of cuspid retraction a slight movement of 0.4 to 0.8 mm was observed in the non-compressed quadrants.* Thereafter, there was a steady decrease in the mesial-distal width of the extraction sites (Table I and figs. 2, 3, and 4),

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*Since mesial movement of the first molars and second bicuspids were not measured and they remained in a class I molar relationship throughout the treatment, closure of extraction site will be considered only due to distal cuspid movement.

until final closure. In the last 14 days the rate of space closure was slower.

In the "compressed" quadrants the cuspid movement during the first week was negligible. In general, during the first 28 days the movement was slower than the non-compressed quadrants, however, a sharp increase was observed thereafter (Table I and figs. 2, 3, and 4). This increase in the rate of distal movement of the cuspid was, however, not sufficient to compensate for the earlier lag. This resulted in a longer period for cuspid retraction in all the quadrants where the extraction sites were "compressed" as compared to the non-compressed sites. Overall, the cuspids moving through the "compressed" sites took an average of 14 more days for final closure as compared to the non-compressed quadrants. A decrease in the rate of movement of the cuspid was also observed in the "compressed" quadrants during the final days of closure of the extraction sites.

The gingival tissue encompassing the extraction site, which included the interproximal tissue mesial and distal to the extracted first bicuspid showed a "crowding" or "bunching" with the distal movement of the cuspid. As the cuspid approached the second bicuspid, the thickening and bunching became more and more pronounced. During retraction, a slight groove was also found mid-way between the approximating teeth. This groove remained in the mid-point throughout the closure,

TABLE I

The time required for cuspid retraction (in days)

QUADRANT	MONKEY # 1	MONKEY # 2	MONKEY # 3
Upper Left	72*	54	60
Upper Right	56	68*	74*
Lower Left	70*	59	58
Lower Right	--	--*	--

* Compressed extraction sites

** No appliance was used to close the extraction sites

TABLE II

Cuspid Retraction Schedule

		DAYS					
QUADRANT	MONKEY	7	14	28	42	56	72
		Values in mm.					
UL	1*	0.1	0.4	1.5	3.8	4.7	6.1
	2	0.6	1.0	2.9	4.8	6.2	**
	3	0.8	1.2	3.2	4.5	5.9	**
UR	1	0.4	1.5	3.1	5.1	6.0	**
	2*	0.0	0.6	2.0	4.3	5.4	6.3
	3*	0.2	0.7	1.8	4.0	5.2	6.2
LL	1*	0.1	0.3	1.4	3.9	5.6	7.8
	2	0.6	1.6	3.0	5.3	7.4	**
	3	0.5	1.8	3.6	5.8	7.6	**

* Extraction sites were compressed

** Extraction site was closed

indicating its distal movement with the progress in the cuspid retraction. The groove ran from tip of the interproximal tissue towards the base of the alveolar bone and was found on both buccal and lingual sides (figs. 5, and 6). After complete closure of the extraction sites, the "bunched" gingival tissue was found projecting on the buccal and lingual sides from the contracting points of cuspids and second bicuspids. The "bunching" of the extraction site tissue was noted in all orthodontically closed extraction sites regardless of post-surgical treatment.

In each quadrant where the cuspid was moved distally, a red spot was noted on the gingival tissue at the mesial side of the cuspid. This was first described by Atherton (1970). This area was of bright red color and had the appearance of granulation tissue.

HISTOLOGICAL EXAMINATION:

The findings will be described separately for the compressed and non-compressed extraction sites.

A. Control non-compressed quadrants (Figs. 7, 8 and 9).

The lower right quadrants of monkey no. 1 and 3 belonged to this group. Both monkeys were sacrificed on the 75th day after the start of the orthodontic treatment. The principal area of interest in this group was the repair of the extraction site.

The overall histological picture looked normal. The transseptal fibers were found to span from cuspid to the second bicuspid. More collagen fiber bundles were seen in the area of the epithelial attachment. A group of these fibers entered into the gingival papilla and rest of the group travelled towards the extraction site. The fibers in abundance in the extraction site were examined but their horizontal direction as seen in the mesio-distal sections was disoriented. In the extraction site the transseptal fibers intermingled with the fibers of the opposite side (fig. 7). Immature bone was observed in the socket of the extracted first bicuspid.

The periodontium of the cuspid appeared essentially normal except for very slight stretching of the principal group of fibers on the mesial side. The periodontal fibers on the distal side of the second bicuspid also appeared slightly stretched (fig. 8).

The oxytalan fibers were seen in abundance in the transseptal area. The largest quantity of oxytalan fibers was seen near the epithelial attachment. These fibers were seen running parallel to the collagen fibers in the transseptal area in the mesio-distal sections. A large number of oxytalan fibers, running in several directions, were observed in the area of the extraction site. In the area of principal fibers, the oxytalan fibers were seen emerging from the cementum and running into the periodontal ligament. However, no fibers were seen crossing the entire span of the periodontal ligament. The oxytalan fibers were thicker upon emergence from the cementum and were found to be more slender as they passed into the periodontal ligament. In some areas they were also seen passing from alveolar bone into the periodontal area. Few fibers were seen running parallel to the long axis of the tooth within the periodontal ligament. (fig. 9).

B. Control compressed quadrant (figs. 10 and 11).

Lower right quadrant of monkey no. 2 belonged to this group. The histological picture of bone and periodontal ligament appeared similar to the one seen in the controlled non-compressed quadrants. The buccal and lingual cortical plates were in closer approximation to each other.

C. Treated "non-compressed" quadrants (figs. 12, 13, 14, 15, 16, 17, 18, 19, 20, and 21).

The "bunched" gingival tissue and the cleft were clearly observed in the histological sections. The epithelial border of the "bunched" tissue appeared wavy and less keratinized. The rete pegs were several shapes and no standard arrangement was seen.

The transseptal fibers appeared to run into the marginal gingiva from the area of the epithelial attachment (figs. 12

and 13). The transseptal fibers running from the distal of the cuspid to the mesial of the second bicuspid were found bunched in a rolled appearance as seen in mesial distal sections (fig. 14). However, no specific interruption in the running pattern of the transseptal fibers was observed as was seen in the extraction areas in control non-compressed quadrants.

On the tension side (figs. 15, 16, 17, 18) of the retracted cuspid the collagen fibers appeared stretched (fig. 15). The periodontal space showed a greater increase at the alveolar crest compared to the same area at the apical 1/3rd of the root. The collagen fibers of the principal group of the periodontal membrane were running in a slightly occlusal direction towards the cementum. Osteophytic spicules of bone was seen to be following the collagen fibers in this direction. The cemental border appeared intact.

On the pressure (figs. 19, 20, and 21) side of the retracted cuspid, the alveolar crest was found to be considerably destroyed and also the apical 1/3rd root area on the mesial of the cuspid. The periodontal space in the upper 1/3rd appeared to be at a minimum and gradually increased in size towards the apical end. Large areas of bony resorption and osteoclastic activity were noted on the pressure side. The cementum was resorbed only in ten isolated areas (fig. 20).

The oxytalan fibers running along with transseptal fibers were also found to be bunched and folded. These fibers appeared to be thicker in the middle region of the transseptal areas as compared to the fibers emerging from the epithelial attachment (fig. 14). Many oxytalan fibers along with the collagen fibers entered the "bunched" gingival tissue. More oxytalan fibers were observed on the tension side than on the pressure side (fig. 15). The quantity of these fibers was greater in the mesial coronal and distal apical thirds of the tension areas. Near the cemental side the oxytalan fibers appeared stretched, long and slender. In the middle region of the periodontal space of the pressure side the oxytalan fibers appeared stretched near the cemental surface and disoriented in the middle region (fig. 21).

D. Treated "compressed"quadrants.

The collagen fibers near the epithelial attachment and in the gingival papilla appeared the same as those observed in the "non-compressed" group. Only significant difference found was at the middle of the interproximal area between the cuspid and the second bicuspid where the transverse continuity of the transseptal fibers was completely lost and they appeared bunched or coiled. This phenomenon appeared relatively more severe in this group as compared to the group where extraction sites were not compressed (fig. 22).

On the mesial side of the retracted cuspid the transseptal fibers appeared less stretched and at several areas they appeared slightly coiled (fig. 23).

On the tension side the periodontal space appeared very wide at the coronal third of the root (fig. 24). The osteophytic bony spicules were seen running obliquely following the direction of the periodontal fibers. The collagen fibers appeared very stretched and at places they were broken. A great amount of osteoblastic activity was found on the bony side (figs. 26, 27). The oxytalan fibers were also found to be abundant, taut, and stretched (fig. 28).

On the pressure side the alveolar crest was severely resorbed by osteoclastic activity. The continuity of the cementum was broken at numerous places by resorption (figs. 28, 29). At some areas the resorption of cementum was extensive. The resorbed areas were filled with the periodontal fibers, mesenchymal cells, cemental debris. The presence of oxytalan fibers was also found to be in great abundance in the resorbed areas of the cementum.

The interdental alveolar bone was resorbed very severely at several areas. Various areas of Howships lacunae (fig. 30), were also observed. The marrow spaces of the interdental alveolar bone appeared very large indicating areas of "undermining" resorption.

The extent of resorption of bone and cementum observed in this group was not noted in the previous group where the extraction sites were not compressed.

The oxytalan fibers were also relatively greater in number on both tension and pressure sides as compared to the areas seen in the non-compressed group.

DISCUSSION

The most significant observation of the present study was that cuspids which were retracted through compressed extraction sites took a longer period of time to approximate with the second bicuspids when compared with those moved through non-compressed extraction sites. No study in the literature was found which was conducted with the same objectives as the present one. However, the possible reasons for the slowness of the cuspid retraction through the compressed extraction sites can be explained by the histological observations of the present study and by an extrapolation with related studies on tooth movement.

The compression of the extraction sites as observed in the histological cross sections caused a collapse of the buccal and lingual or palatal cortical plates to the extracted sockets. This collapse resulted in a smaller volume of trabecular bone in the extraction site. It was also observed that compression resulted in relatively small marrow spaces at the site of new bone formation in the area of the socket. (Reitan (1953) mentioned that one of the most important variable factors in the tooth movement is the type and condition of the local bone prior to the initiation of tooth movement. He also observed a considerable amount of hyalinization of the periodontal membrane in cases where the bone was found devoid of or having less open marrow spaces. An initial lag in the cuspid movement through the compressed extraction sites observed in the study here present can be attributed to the possible hyalinization of the periodontal membrane on the pressure side.

Gianelly (1969) emphasized that the role of the vascular system is to furnish the essential nutrients and oxygen for the energy required for the process of bone resorption. It has also been mentioned that blood vessels may be the source of the osteoclasts (Trueta, 1963). The compression of the extraction sites in the present study possibly resulted in the diminished vascular supply to the area between the cuspid and second bicuspid. This probable diminished vascular supply might have been a potent factor in the slowness of the cuspid retraction through the compressed extraction sites.

Reitan (1953) mentioned that adult patients have a dense laminated bony tissue with small marrow spaces. He also found that periodontium of adult teeth reaches the proliferation stage later than the periodontium of younger individuals during orthodontic tooth movement. The alveolar bone at the compressed sites and its response to the initial tooth movement as found in the present study appears to be similar to that described by Reitan (1953).

Frost (1963) explained that the compression of bone inhibits the osteoclastic;activity and permits the osteoblastic activity while its absence causes the reverse phenomenon. He further stated that the surface signals generated by deformed bone combine to operate as a negative feed-back mechanism in which cell activities are minimized. McLean and Urist (1968) stated that the local stimulus that induces the osteoblastic and osteoclastic activity of a bony trabecula is attributed to surface electric currents. They stated that bone is piezoelectric and thus generates electric currents when mechanically deformed. Diminishing of electric currents incites osteoclastic activity and bone resorption (Basset, 1964; Epker and Frost, 1965). Pressure exerted during the compression of the extraction sites presumably disturb the crystalline structures of the adjacent bony tissues and thus disturbing piezoelectric currents. The resultant inhibition of osteoclastic activity (Frost, 1963) might have been responsible for the almost negligible distal cuspid movement observed during the first 7 days of the present experiments. Even during the first 28 days the movement was appreciably slow when compared to the movements of the cuspid in the non-compressed quadrants.

The longer period taken by the cuspids to travel through the compressed extraction sites can be explained also by

(a) closeness of the buccal and lingual cortical plates and less trabecular bone in the healed extraction sites, (b) occlusion of the bone marrow spaces and a reduction of the blood supply to the alveolar bone at the extraction sites, (c) and a disturbance in the piezoelectric response of the bone due to compression thereby inhibiting the osteoclastic activity.

Another interesting phenomenon observed was a sharp increase in the rate of distal cuspid movement in the compressed quadrants between the treatment days of 28 and 42. After the day 42, the average rate of distal movement was almost similar to the distal movement in the non-compressed sites. The spurt after the treatment day 28 can be explained by the phenomenon called "undermining resorption" (Sandstedt, 1904). Several areas of "undermining resorption" were observed in the specimens from the compressed sites. In these sections the cementum of the cuspids on the pressure side also exhibited considerable resorption. The root resorption and "undermining resorption" have been related to the tooth movement caused by heavy forces. The application of heavy forces in the present study can be excluded by the fact that the root surface of the cuspids on the compression side of the non-compressed quadrants showed very little root resorption. Great care was taken during the experiment to exert the same amount of force on all cuspids.

The explanation which can be given for the root resorption and "undermining resorption" is the possible longer period of hyalinization and a reduction in blood supply. A reduced osteoclastic activity in the vicinity of the cuspid periodontium can also not be ruled out on the basis of the statements mentioned in the preceding paragraphs. However during the period of possible hyalinization and slow movement of teeth the exerted force was dissipated through the resorption of the cemental surfaces.

During the last 10 days before the complete approximation of the cuspid with the 2nd bicuspid both in the compressed and non-compressed quadrants a noticeable slowness in rate of the distal cuspid movement was observed. This lag can be attributed to the bunching of the gingiva between cuspid and the bicuspid, physically inhibiting their final approximation. This "bunched" gingival tissue was even observed projecting from the buccal and lingual embrasure areas after complete closure. Atherton (1970) explained that the bunching of the gingival tissue might be a physical cause of relapse after the approximation of teeth through an extraction sites. His observations were also supported by Edwards (1970). They both noted that a tooth moving through an extraction site does not move through the gingival tissue but rather pushes it toward the side of pressure.

Clinically, relapse after retraction of protruded maxillary incisors, occurs when the retention period is not sufficiently long. It is the belief of the author that the major part of this relapse is contributed by the bunching of the fibrous palatal tissue and the rugae adjacent to the lingual surfaces of the maxillary incisors. The histological and clinical findings of the present study and those observed in the patients indicate that there is no physiological breakdown of the soft tissues during the tooth movement and immediately after the end of the treatment. This necessitates the requirement of retention of the moved teeth for longer periods so that gingiva, palatal tissue and periodontal fibers can adapt themselves to the newly acquired positions of the teeth.

The transseptal collagen fibers were found coiled, bunched, and disrupted in the middle of the approximated teeth both in the compressed and non-compressed quadrants. The only explanation for this finding is that the collagen fibers found between the cuspid and second bicuspid after the extraction of first bicuspid do not resorb but rearranged. With the progression of distal movement of the cuspid these fibers are pushed distally. They remain between the two approximated teeth in a coiled position. This behavior of the transseptal fibers observed in the present study supports the observations of Erikson et al. (1945). Our findings also concur with those of Huettner (1958) who stated that the transseptal fibers are most resistant to damage and they do not necortize easily. He also found that the transseptal fibers elongate easily as was observed in the present study on the tension side of the cuspid.

The transseptal fibers have been considered a major cause of relapse by almost all the workers who have done research in this field. It has also been shown that their power to reorganize is very poor. Reitan (1959) found in his classic experimental study that the transseptal fibers were still displaced even after 232 days of retention of moved teeth. Their role in relapse has been thought to be so powerful that several researchers have mentioned an excision of the supra-alveolar and transseptal fibers immediately after the end of the orthodontic treatment (Skogsberg, 1932; Thompson, 1959a, 1959b,; Wiser, 1961; Boese, 1969; Edwards, 1968). No attempt was made in the present study to investigate the relapse of the moved teeth. However, the presence of stretched collagen transseptal fibers on the mesial side of the cuspid and coiled collagen fibers found between the cuspid and second bicuspid indicates their potentiality to bring about relapse.

The characteristic of oxytalan fibers before and after the closure of the extraction sites was also studied. These deep purple fibers have received considerable interest recently regarding their role in the orthodontic tooth movement and their subsequent role in retention. Fullmer (1958) described them as "elastic-like" connective tissue. Their similarity with the elastic fibers has also been shown by the electron microscopic study of Carmichael and Fullmer (1966). The arrangement of the oxytalan fibers observed in the present study basically agrees with the findings of Fullmer (1958), Goggins (1966) and Edwards (1968). However, in some instances exceptions were noted. Oxytalan fibers were found in great abundance (more in the compressed quadrant) in the center half of the transseptal area between the cuspid and second bicuspid. This finding is contrary to that of Edwards (1968) who found no oxytalan fibers in this area in both his control and experimental animals. The difference can be explained by a difference in the design of the experiment and the experimental animals in the present study and that of Edwards who used dogs. Also, Edwards (1968) did not extract teeth in his study. The presence of large numbers of oxytalan fibers in the center half of the moved teeth can be attributed to (a) stress caused by extraction of first bicuspids, (b) stress caused by inflammation resulting from lack of hygiene in the embrasure area, (c) stress caused by forces of mastication in the area, and (d) stress caused by orthodontic forces. The comparatively greater abundance of oxytalan fibers in the middle region of transseptal collagen fibers of the compressed quadrants can also be explained by the stress caused by the compression of extraction site before the initiation of the cuspid movement. This increased amount of oxytalan fibers was also observed in one quadrant where the extraction site was compressed but no tooth movement was initiated.

The oxytalan were also found in more quantity associated with the principle fibers of the periodontal membrane on the tension side as compared to the pressure side regardless of whether or not there was compression of the extraction sites. The relationship of the oxytalan fibers with the stress mechanism has been explained by several research workers. It has been shown that oxytalan fibers are found in great abundance in tendons, ligaments, blood vessels, pathological tissue and after gingivectomies (Fullmer, 1959b, 1961, 1962; Tedeschi and Sommers, 1962; Hasegawa, 1960).

It was out of scope of the present study to determine the role played by the large number of oxytalan fibers in retention of the moved teeth. Boese (1969) in his experimental work on monkeys stated that displaced oxytalan fibers are the primary cause of relapse of orthodontically rotated teeth. He based his conclusions on the assuptions of other investigators that these fibers have an elastic property (Fullmer and Lillie, 1958). The present study could not throw any additional light on the property of these specialized fibers. However, they might increase in number in orthodontically moved quadrants as a protective mechanism against the abuse of the normal tissue due to orthodontic forces. Rannie (1961) postulated that the oxy-talan fibers might have a possible role in the anchoring of the teeth. This explanation is valid if the oxytalan fibers have a protective function rather than the result of an inflammatory response.

CONCLUSIONS

1. The cuspids moved distally through the compressed extraction sites took a longer period of time compared to the cuspids moved distally through the non-compressed extraction sites.

2. The lag in the cuspid movement through the compressed extraction sites was more evident during the first twenty eight days of the treatment. This was explained as being due to the initial period of hyalinization.

3. The excess gingival tissue found between the cuspid and 2nd bicuspid after their approximation was thought to account for the slowness observed during last stages of cuspid retraction.

4. The slowness of cuspid movement through the extraction site was attributed to more cortical bone and less trabecular bone in the healed extraction sites, an occlusion of marrow spaces, a reduction of the blood supply to the alveolar bone at the extraction site, and a disturbance of the piezoelectric response of the alveolar bone at the extraction site.

5. The cuspids moved through the compressed sites showed considerable root resorption and "undermining resorption" of bone on the pressure side.

6. The transseptal fibers along with the oxytalan fibers were found in bunched and coiled positions in the middle of the transseptal area indicating their reluctance to reorganize as did the alveolar bone.

7. The disturbance in the arrangement and excess of oxytalan fibers indicated their reluctance to reorganize as did the alveolar bone.

8. The disturbance in the arrangement and excess of oxytalan fibers observed in both compressed and non-compressed quadrants after cuspid retraction was attributed to the protective response of these fibers.

SUMMARY

The object of the present investigation was to study the movement of cuspids through compressed and non-compressed extraction sites. Three Macaca Nemestrina monkeys were used. The first bicuspids of all the monkeys were extracted. The lower right quadrant of each monkey served as a control, no orthodontic tooth movement was done in these quadrants. In the remaining quadrants cuspids were retracted through the extraction sites using segmented arches. The extraction sites of four quadrants where tooth movement was accomplished were compressed immediately following the extractions. Only one extraction site of the control quadrants was compressed. The progress of cuspid retraction was studied clinically and the rate of distal cuspid movement was measured at weekly intervals. At the end of cuspid retraction the animals were sacrificed and all the control and experimental quadrants were studied histologically.

The clinical examination conducted at various intervals revealed that distal cuspid movement was initially slower through compressed extraction sites than for non-compressed sites. Cuspids moving through compressed extraction sites required an average of 14 more days for complete retraction. At the

termination of cuspid retraction a considerable amount of excess gingival tissue was observed projecting from the embrasure areas between the retracted cuspid and the 2nd bicuspid.

The histological observations showed root resorption and "undermining resorption" on the pressure side of the cuspids moved through the compressed extraction site. Coiled and bunched transseptal fibers were observed in both compressed and non-compressed approximated areas. Overall tissue damage was greater in compressed sites.

Special staining procedures were employed to study the behavior of oxytalan fibers before and after the closure of the extraction site. The oxytalan fibers were found emerging from the cementum into the periodontal membrane. In mesio-distal histological sections the majority of the oxytalan fibers were also found in the same sections running in an apico-occlusal direction. The oxytalan fibers along with the collagen fibers of the periodontal membrane appeared stretched on the tension side and bunched and coiled on the pressure side. At the neck of the tooth the fibers were found emerging horizontally along with the collagen transseptal fibers. Several groups of oxytalan fibers were found entering the marginal gingiva. In the middle of the transseptal area oxytalan fibers, along with the collagen fibers appeared to have lost their horizontal direction and continuity. In this area the fibers were found bunched and coiled. This observation was found to be more severe in the compressed quadrants.

The findings of the present study are discussed by an extrapolation of the visual and clinical observations as well as with the findings of the related articles. The longer period taken by the cuspids moved through the compressed extraction sites was attributed to a combination of the following factors: (a) compression causes a closeness of the buccal and lingual or palatal cortical plates resulting in less trabecular bone and more cortical bone in the healed extraction site, (b) compression causes an occlusion of the bone marrow spaces and a possible reduction of the blood supply to the alveolar at the extraction sites, (c) compression might have disturbed the piezoelectric response of the bone thereby inhibiting the osteoclastic activity. It was also noted that the excess gingival tissue at the approximated site might be instrumental in the slow rate of cuspid movement during the terminal phases of cuspid retraction through the compressed and non-compressed extraction sites. The role of excess gingival tissue and disturbance in the arrangement of the transseptal gingival fibers were discussed in relation to the relapse of orthodontically moved teeth.

The specific response in the arrangement and distribution of oxytalan fibers was observed in both compressed and non-compressed quadrants. It is assumed that the oxytalan fibers are a part of the protective mechanism in response to the abuse to the periodontal ligament by orthodontic tooth movement in as much as their number increased several fold in the stress area.

Further experiments on the relapse tendencies of the teeth moved through the compressed extraction site would throw additional light on the subject discussed in the present study.

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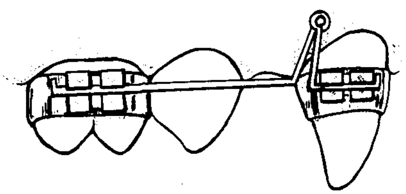
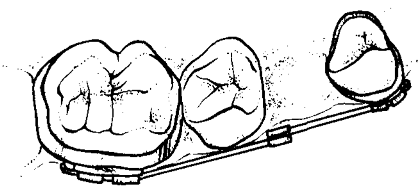
Figure 1. Diagrammatic representation of the buccal and occlusal views of the orthodontic appliance used

FIGURE 1
CUSPID RETRACTION APPLIANCE

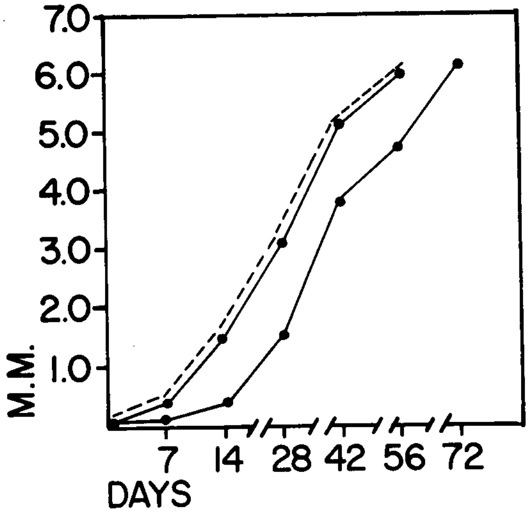


Buccal view



Occlusal view

FIG. 2
Degree of Cuspid Movement
(Monkey #1)



------ Upper Right, Non-"Compressed" Extraction Site

—— Upper Left, "Compressed" Extraction Site

FIG. 3

Rate of Cuspid Movement (Monkey#1)

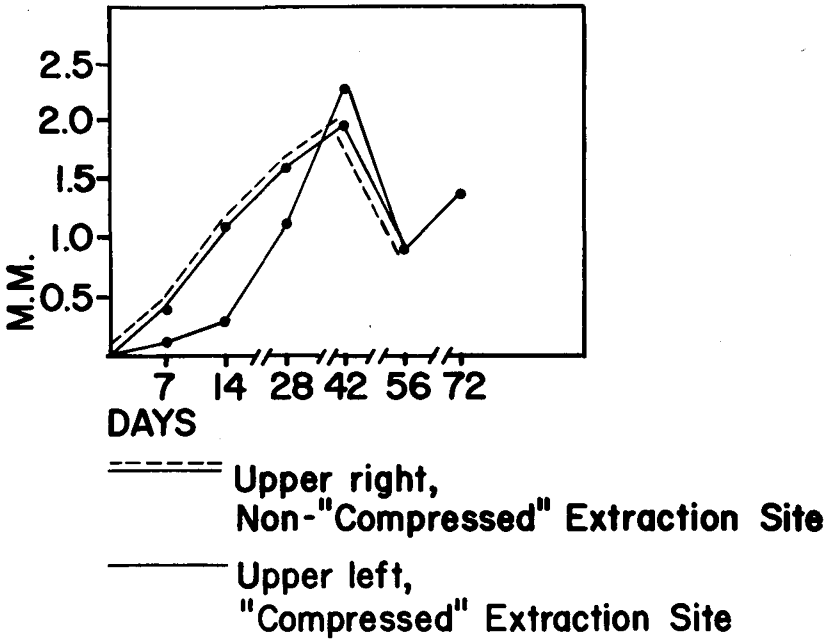


FIG. 4
Average Rate of Cuspid Movement in the Upper Arch

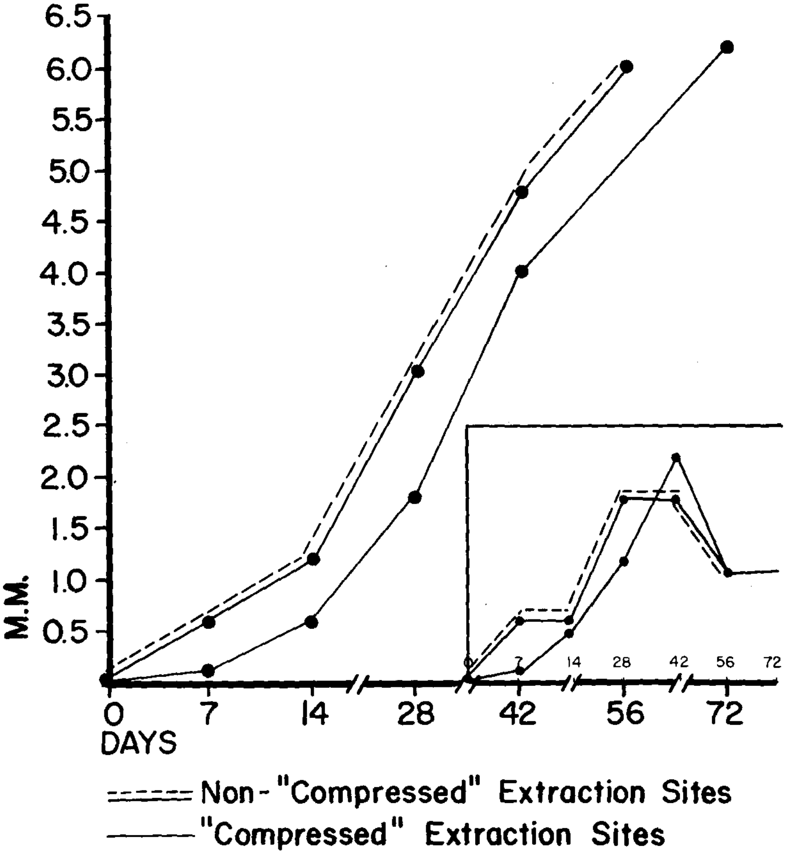


Figure 5. An occlusal view of the appliance in the upper arch. Note one side was tied back and the appliance was removed because the closure of the extraction site required less time in the non-compressed quadrant.

Figure 7. Control non-compressed quadrant. Sagittal Section. Note the transseptal collagen fibers in the area of first bicuspid extraction. At the extraction site their continuity is lost and they appear to intermingle with the collagen fibers (arrows) of the other side. PA-AF-H stain. (X240).

Figure 8. Control non-compressed quadrant. Cross-section. Purple colored oxytalan fibers can be seen emerging from the distal surface of the root of the maxillary cuspid (arrows). The periodontal fibers appear slightly stretched PA- AF-H stain. (X240).

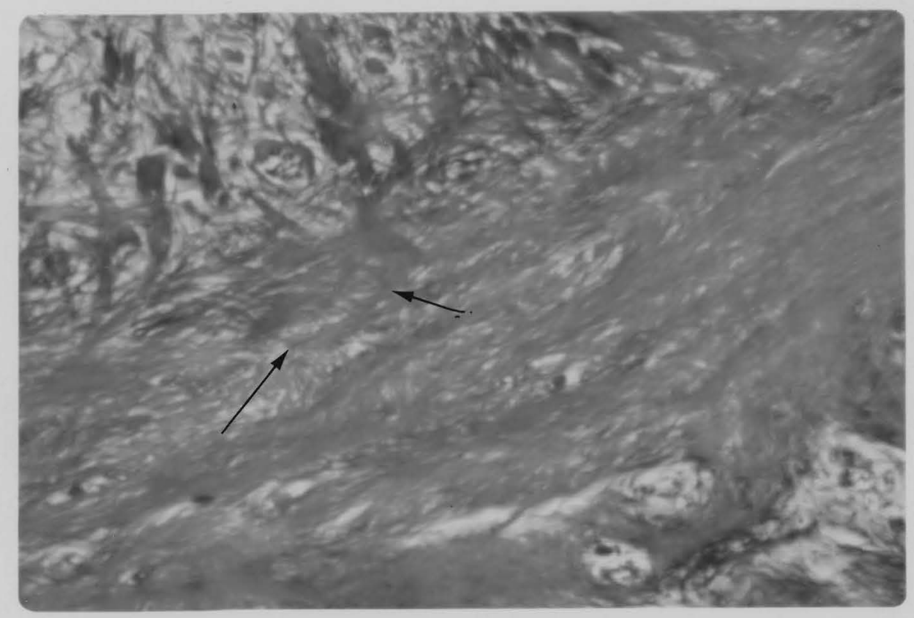
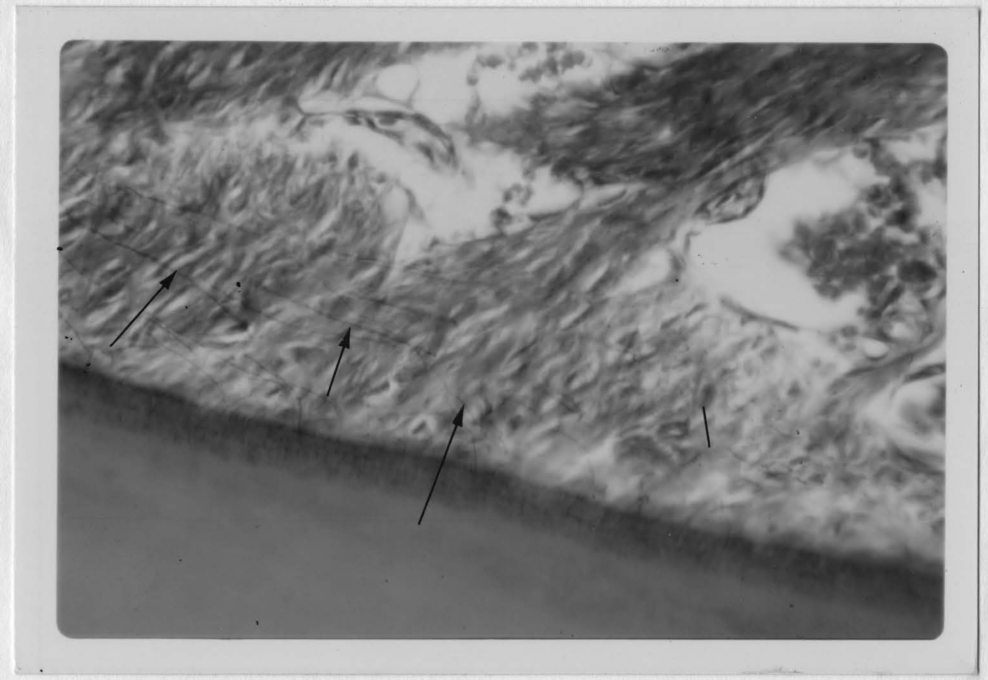


Figure 9. Control non-compressed quadrant. Sagittal Section. Note the orientation of the oxytalan fibers in the periodontal membrane of the distal surface of the root of the maxillary cuspid. Oxytalan fibers can be seen emerging from the cementum and the long oxytalan fibers lying parallel to the cemental surface (arrows). PA-AF-H stain. (X240).

Figure 10. Control compressed quadrant. Sagittal Section. Note the orientation of the transseptal collagen fibers (T) in the compressed extraction site. PA-AF-H stain. (X240).



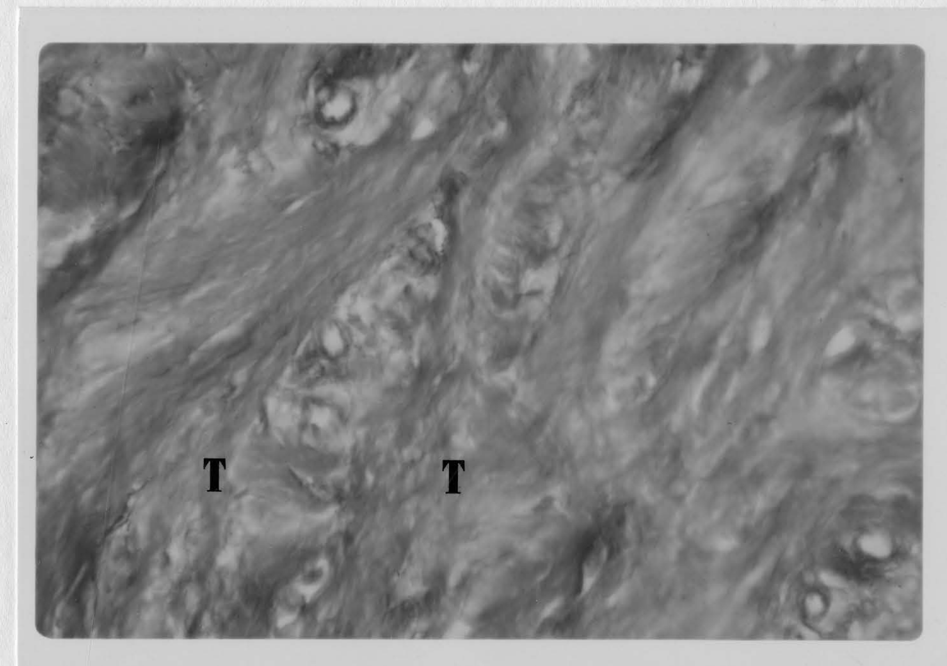


Figure 11. Control compressed quadrant. Cross section. Note the abundance of purple oxytalan fibers in the middle region of the periodontal membrane of the distal surface of the maxillary cuspid root. The oxytalan fibers appear dot-like due to the sectioning of the specimen. PA-AF-H stain. (X240).

Figure 12. Treated non-compressed quadrant. Sagittal section. Note the collagen fibers on the tension side of the mandibular cuspid, emerging from the area behind the epithelial attachment in a bundle-like form. The collagen fibers can be seen running into the marginal gingiva and also towards the transseptal area. The collagen fibers appear taut. PF-AF-H stain. (X120).

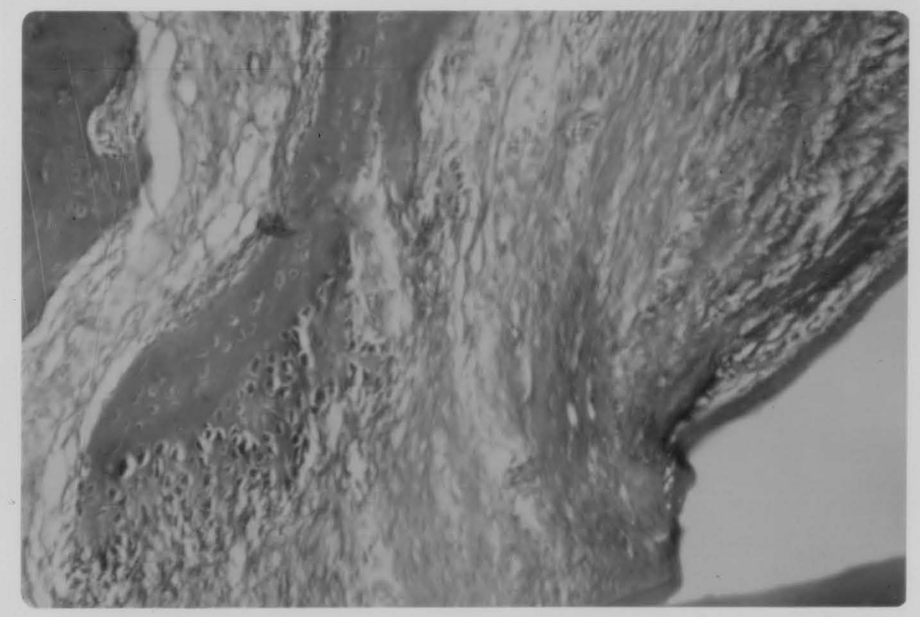
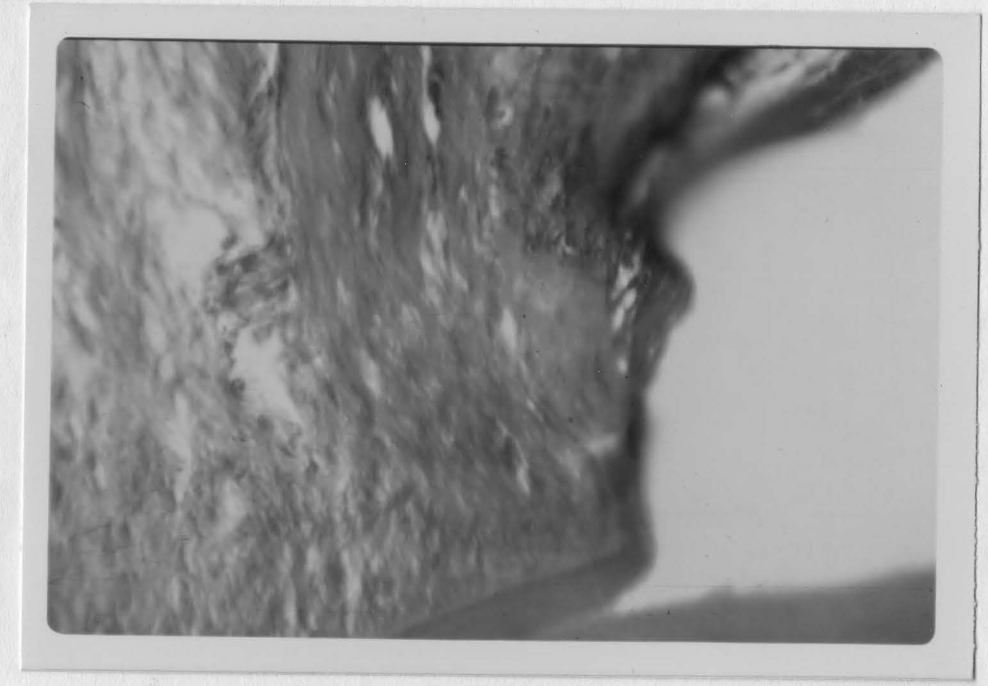


Figure 13. A higher magnification of the collagen fibers shown below the epithelial attachment area. (X240).

Figure 14. Treated non-compressed quadrant. Sagittal section. Note the bunched and wavy appearance of the collagen transseptal fibers in the pressure area between the distally driven cuspid and the bicuspid. Lightly stained oxytalan fibers can be seen criss-crossing the collagen fibers. PF-AF-H stain. (X240).



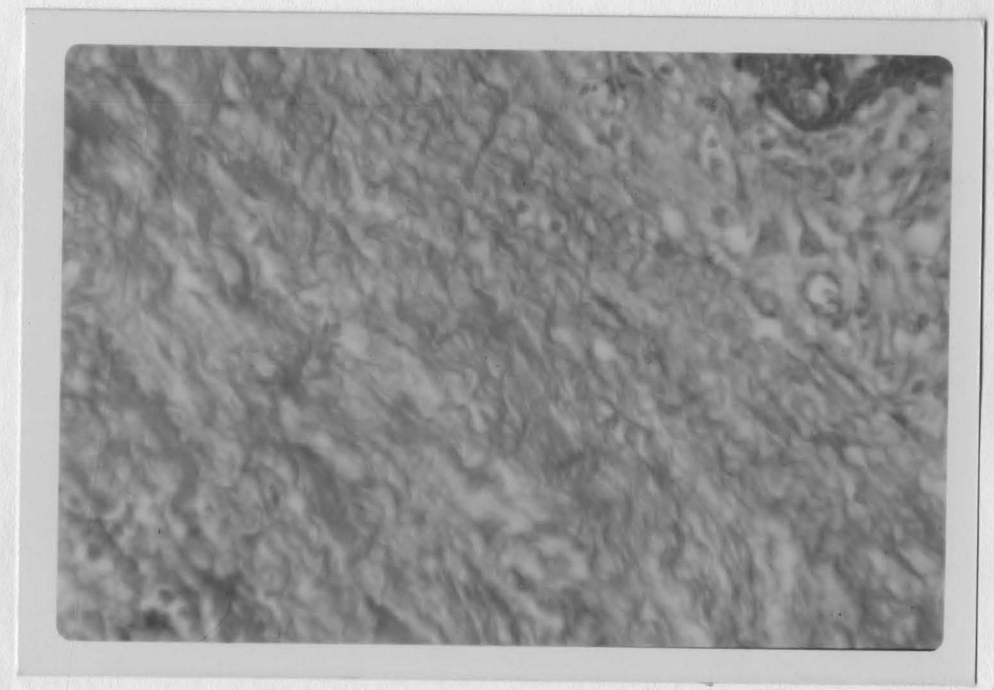
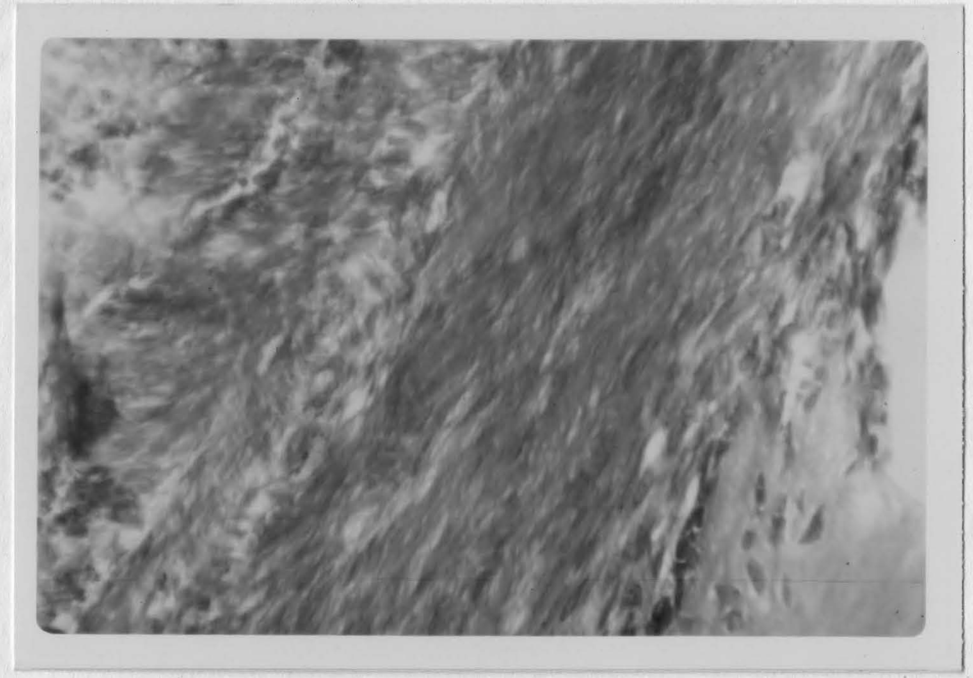


Figure 15. Treated non-compressed quadrant. Sagittal section. The collagen fibers on the tension side in the transseptal area mesial to the distally driven cuspid. The fibers appear more stretched and numerous oxytalan fibers can be seen interweaving the collagen fibers. PF-AF-H stain. (X240).

Figure 16. Treated non-compressed quadrant. Cross section. Note the stretched appearance of the collagen fibers on the tension side of the distally moved cuspid. Numerous lightly purple stained oxytalan fibers can be seen running perpendicular to the cementual surface. Oxytalan fibers can be seen emerging from the whole length of the root surface. PF-AF-H stain. (X240).



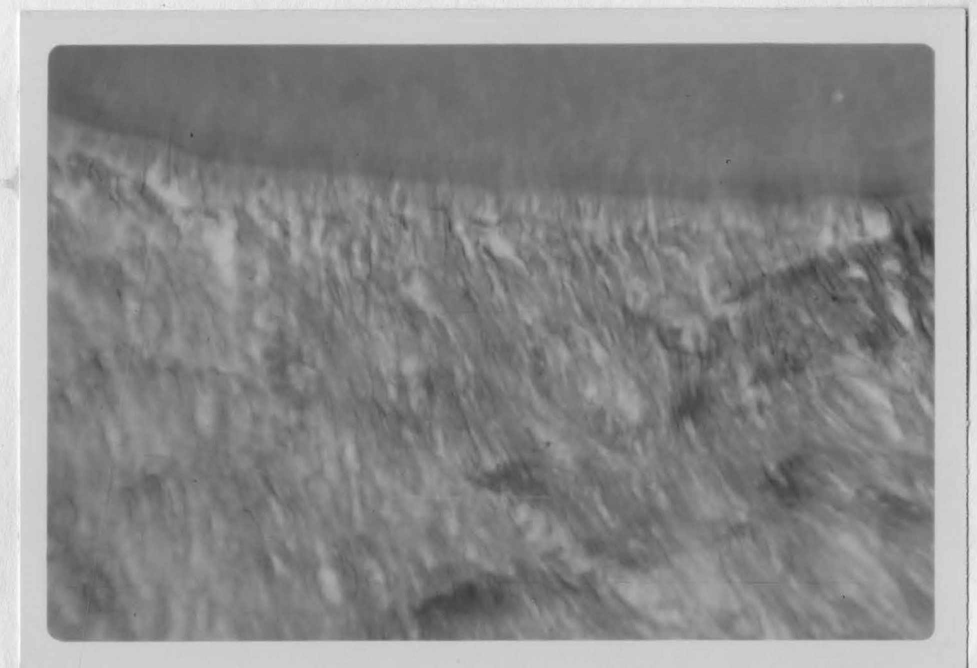
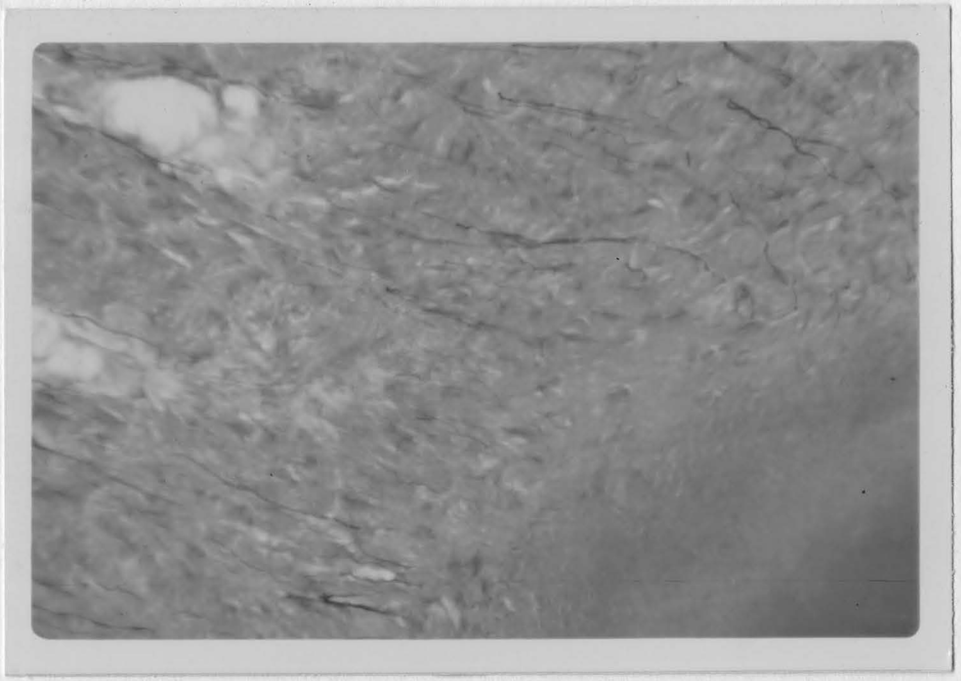


Figure 17. Treated non-compressed quadrant. Cross section. Collagen and oxytalan fibers at the apex of the cuspid on the tension side. Note the stretched appearance of periodontal fibers and abundance of oxytalan fibers. PF-AF-H stain. (X240).

Figure 18. Treated non-compressed quadrant. Sagittal section. Note the stretched collagen fibers running from the cemental surface to the alveolar bone on the tension site. Osteophytic bone (O) can be seen. PF-AF-H stain. (X240).



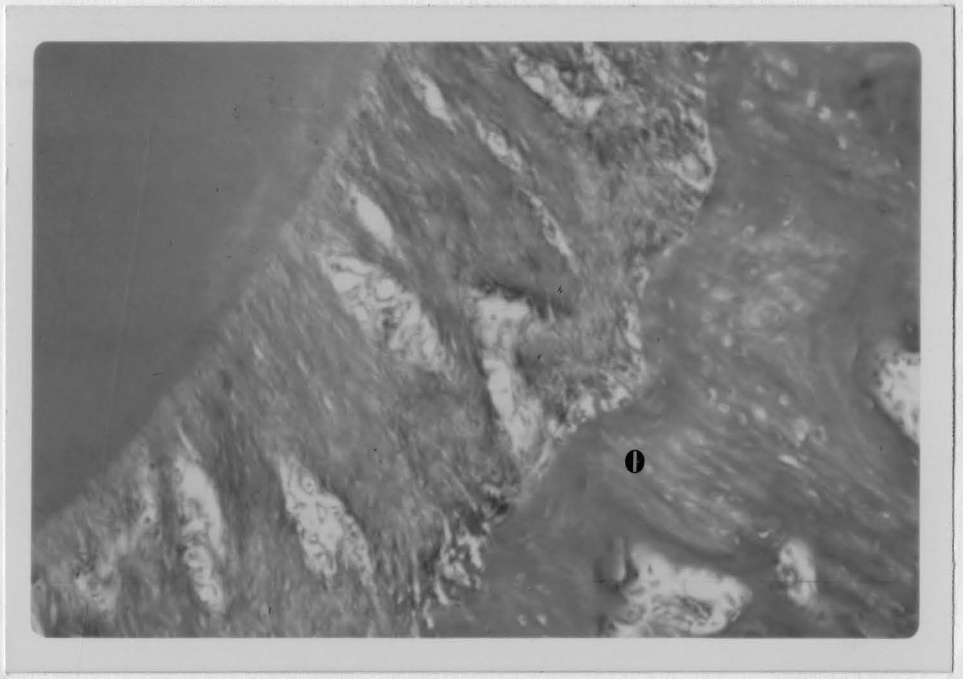
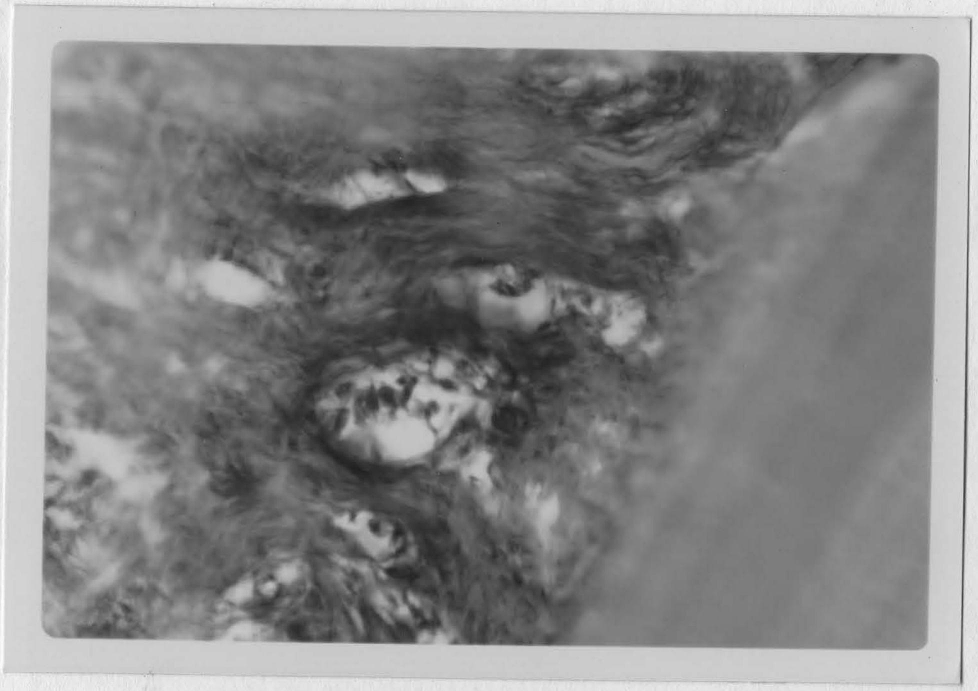


Figure 19. Treated non-compressed quadrant. Cross section. A section of the pressure side of the retracted cuspid. The collagen fibers appear disoriented. PF-AF-H stain. (X240).

Figure 20. Treated non-compressed quadrant. Sagittal section. A section of the middle region of the periodontal space on the pressure side. The oxytalan fibers are stretched near the cemental surface and are disoriented in the middle region of the periodontal space. PF-AF-H stain. (X240).



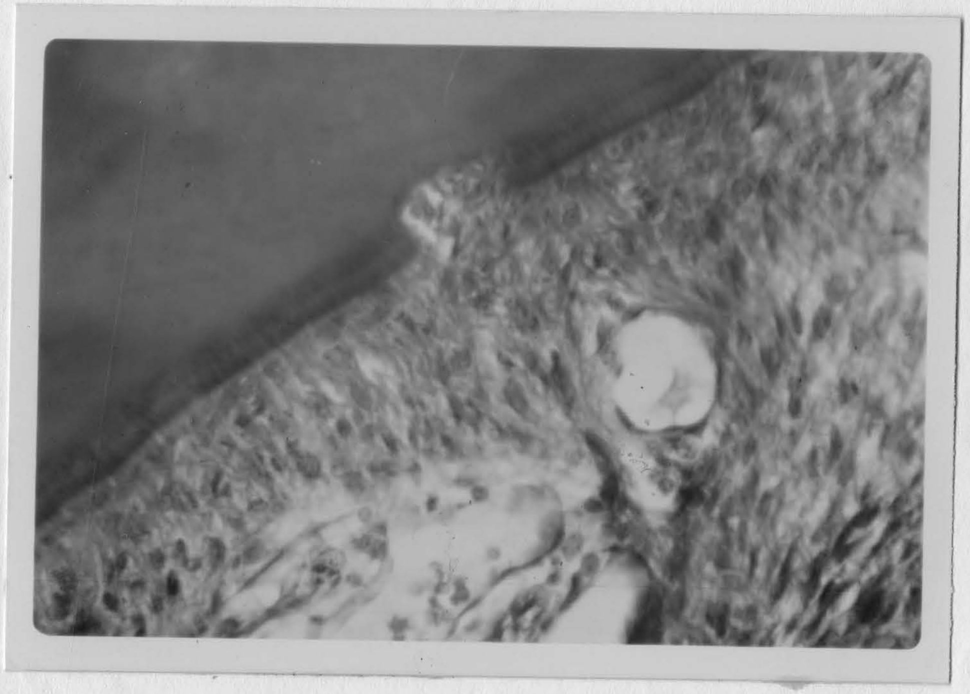
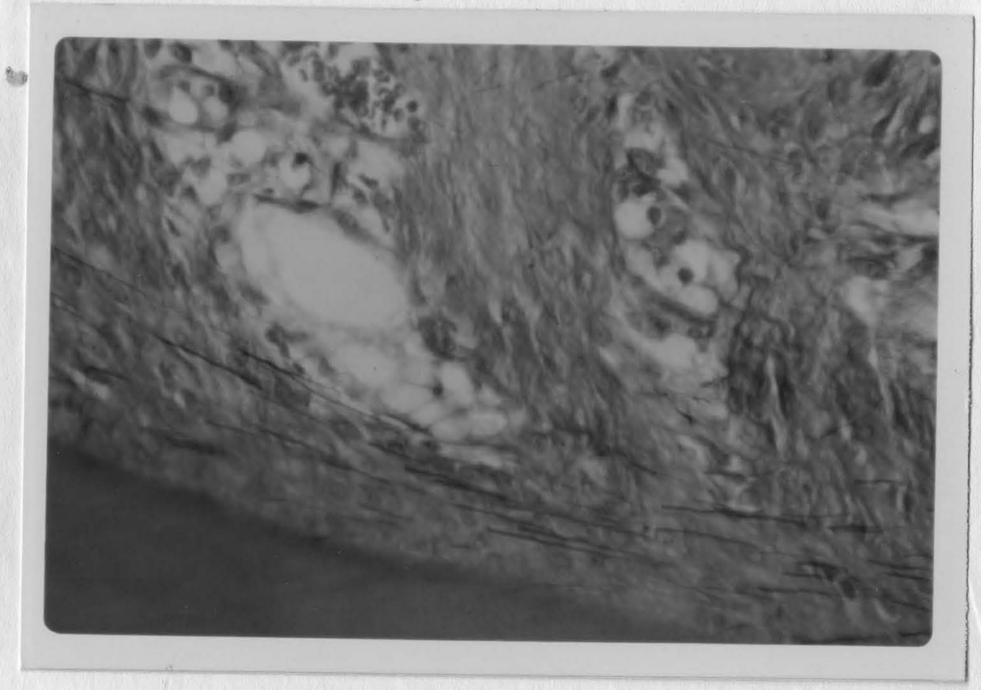


Figure 21. Treated compressed quadrant. Cross section. A section of the transseptal area on the pressure side.

Figure 22. Treated compressed quadrant. Sagittal section. A section of the transseptal area on the pressure side of the retracted cuspid. Note the bunched and coiled appearance of the collagen fibers. PF-AF-H stain. (X240).



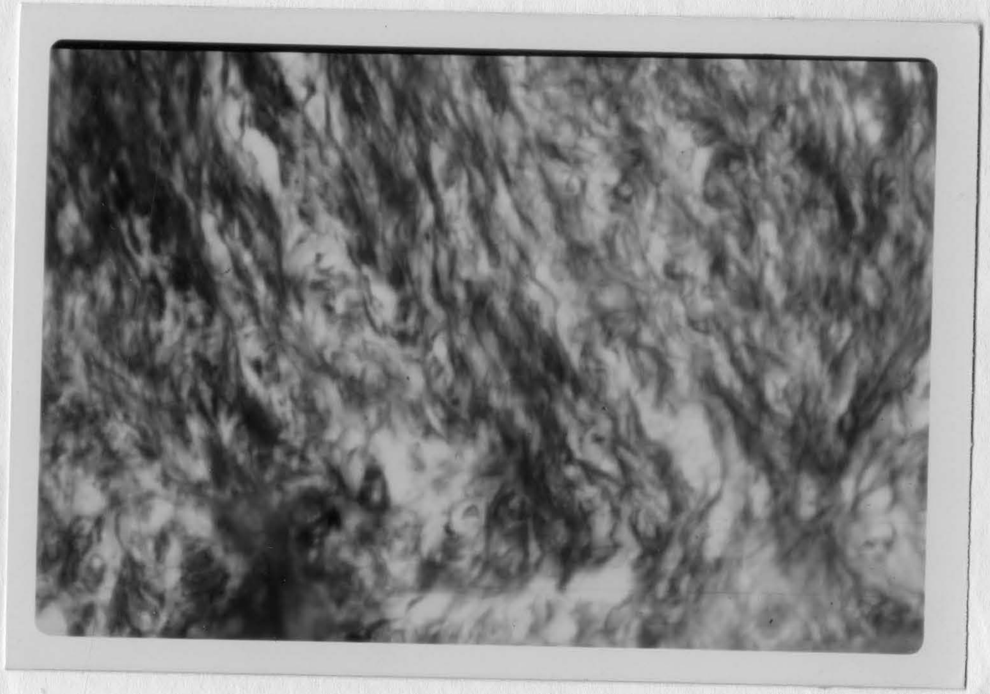


Figure 23. Treated compressed quadrant. Sagittal section. A section of the transseptal area on the tension side of the retracted cuspid. Note the disoriented and coiled collagen fibers. PF-AF-H stain. (X240).

Figure 24. Treated compressed quadrant. Sagittal section. A section noting the stretched collagen fibers at the coronal third of the root on the tension side. Oxytalan fibers can be seen emerging from the cementum. PF-AF-H stain. (X240).

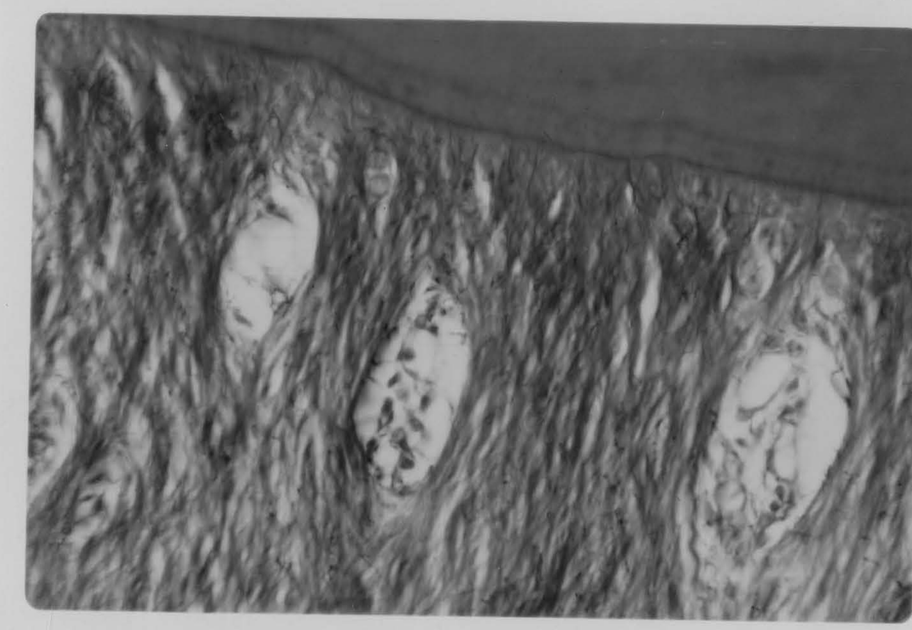
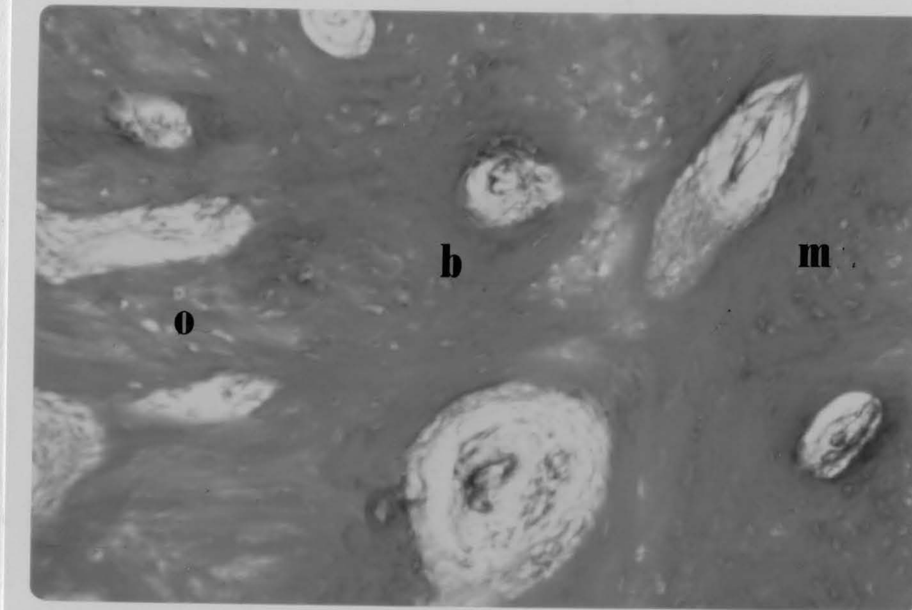


Figure 25. Treated compressed quadrant. Cross section. A section through the tension side of the retracted cuspid. Note the abunance of oxytalan fibers. PF-AF-H stain. (X240).

Figure 26. Treated compressed quadrant. Sagittal section. A section through the tension side of the retracted cuspid. Osteophylic spicules can be seen running in the direction of the stretched collagen fibers. PF-AF-H stain. (X240).

Figure 27. Treated compressed quadrant. Sagittal section. A section through the alveolar bone on the tension side of the retracted cuspid. Note osteophytic bone (O) new bone (B) and mature bone (M). PF-AF-H.stain. (X240).

Figure 28. Treated compressed quadrant. Sagittal section. A high magnification of an area of root resorption on the pressure side of the cuspid. PF-AF-H stain. (X240).



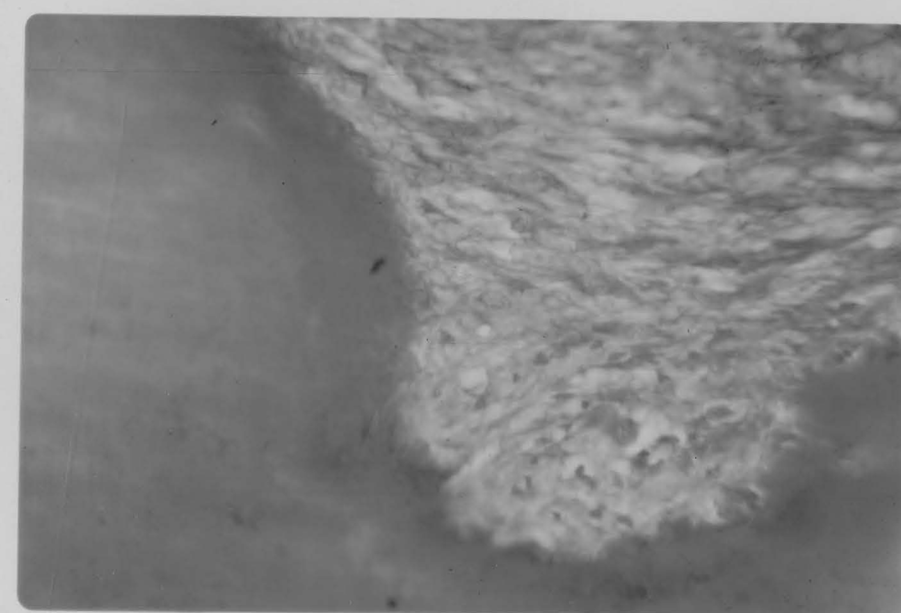
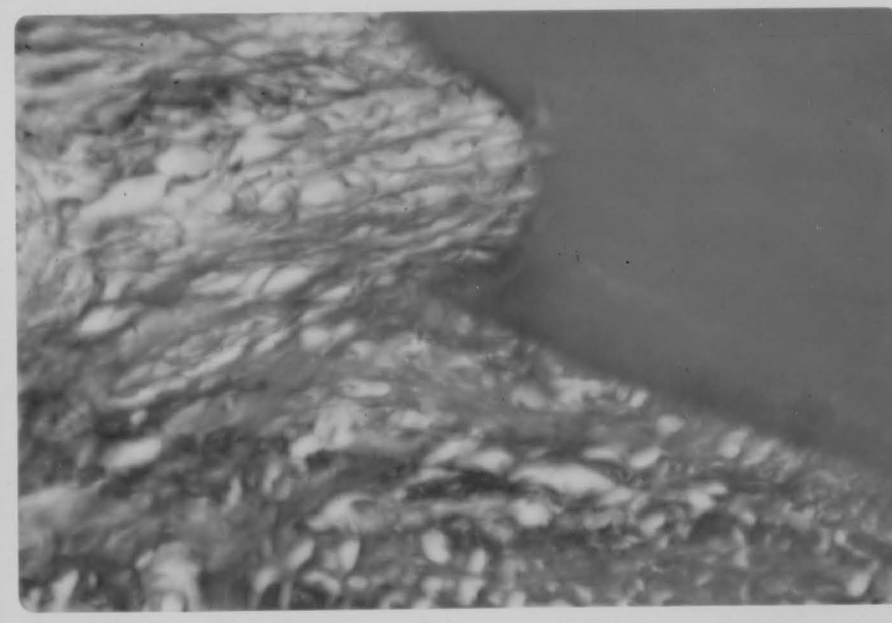
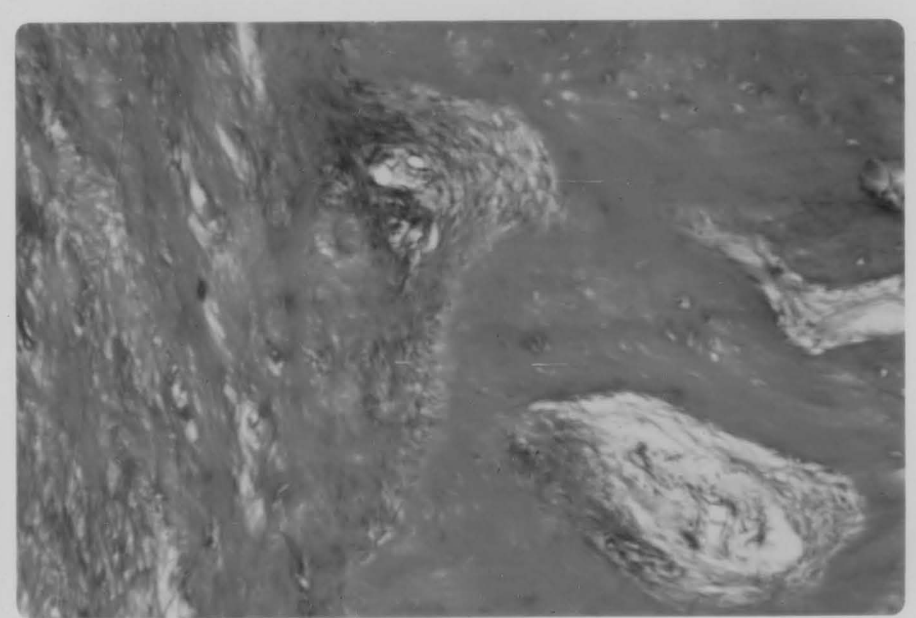


Figure 29. Treated compressed quadrant. Cross section. An area of root resorption on the pressure side. PF-AF-H stain. (X240).

Figure 30. Treated compressed quadrant. Sagittal section. A section through the tension side of the retracted cuspid. A large area of bony resorption can be seen. PF-AF-H stain (X240).





APPROVAL SHEET

The thesis submitted by Billy Abb Cannon has been read and approved by members of the Department of Oral Biology.

The final copies have been examined by the Director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

May. 17. '1972.
DATE

Ravindra Nanda. Ph.D.
Signature of Advisor